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液体粘度が多孔質体中の移動速度に及ぼす影響

The influence of liquid viscosity on infiltration rates in porous media

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1. Introduction

According to the international space exploration roadmap jointly announced by 24 space agencies worldwide, humanity's lunar exploration will begin around 2022 and manned Mars exploration after 2030 (ISECG, 2020). The goal of lunar exploration is 500 days (ISECG, 2020). It is technically and economically challenging to secure food and other supplies for such an extended mission by transportation from the earth (Kitaya, 2016), so it is necessary to produce food inside the spacecraft to reduce the economic burden and to be able to supply food in a closed space. The need to produce food in spacecraft to reduce the economic burden and to be able to supply food in a closed space has been pointed out (Yamashita et al., 2007). There have already been successful attempts to grow plants in spacecraft, but all have been hydroponic and limited in the plants they can grow. Sweet potatoes have attracted attention as a crop grown onboard spacecraft. Sweet potatoes have advantages such as an edible portion ratio of over 95%, being rich in nutrients, and being high in calories (Kitaya, 2016). Since sweet potatoes are mainly cultivated by soil cultivation, it is necessary to elucidate the behavior of water in porous media under the gravity expected in space. When crops are grown in a spacecraft, the liquid to be irrigated is not only distilled water but also liquid fertilizer. In addition, other liquids with various physical properties are expected to be used. Therefore, it is necessary to elucidate the effect of the physical properties of the liquid on the infiltration rate. Moisture movement in capillaries is expressed by the following Lucas-Washburn equation, which considers soil as a collection of capillaries of various diameters (Washburn, 1921).

$$\ell = \sqrt{\frac{\sigma r \cos \alpha}{2\mu} t} \quad (1)$$

where ℓ: infiltration distance (m), σ: surface tension (N/m), r: tube radius (m), α: contact angle (°), μ: viscosity (Pa-s). Equation (1) allows evaluation of the influence of the surface tension σ and viscosity μ of the solution on the infiltration distance ℓ. For NaCl and KCl solutions, the linear relationship between concentration and surface tension σ is very similar. For KCl solutions, there is almost no change in viscosity μ with concentration. This study aimed to elucidate the effect of viscosity μ on the infiltration distance ℓ using these two solutions and distilled water.

2. Materials and Methods

From October 25 to November 5, 2021, we conducted an experiment in which a μG environment was created in a falling tower facility (COSMOTORRE) on Uematsu Electric Corporation (Akahira City, Hokkaido), and the solution infiltrated glass beads packed inside the column. This facility produced μG for about 2.4 seconds, and 11 data were obtained from 6 drops. The particle size of the glass beads was 0.8 mm (BZ-08, Azwan). The glass beads were packed in a cylindrical acrylic column (inner diameter 2.4 cm, height 13.6 cm). The column was placed vertically upward, and a rubber stopper and solenoid valve were attached to the top of the column and secured with vinyl tape. A hole was drilled at the top for ventilation. When the device detected μG, the column and water source were released into the atmosphere, allowing the solution in the porous media to infiltrate. However, the design was such that the solution would not infiltrate if the solenoid valve were closed. The experimental apparatus was fixed on a wooden board (45 cm in diameter and 2.5 cm thick) for integration into the capsule in the COSMOTORRE. A NaCl or KCl solution (Table 1) in a solution reservoir was allowed to infiltrate before the experiment to bring the solution into contact with the glass beads. Three patterns of solution infiltration fronts of 10 mm, 20 mm, and 30 mm were used in the experiments. The solenoid valve was controlled by an Arduino and opened when the accelerometer detected μG for 0.1 seconds. A thermocouple was also attached, and the water temperature was recorded with a CR1000. The infiltration was captured by a video camera (Go Pro Hero8, Go Pro) with a close-up lens attached, and the video was cropped as an image every 0.1 seconds for analysis.

Table 1. Physical properties of liquids used[5].

liquid	concentration (g/g)	surface tension (mN/m)	viscosity (cP)
water	-	72.8	1.002
NaCl solution	0.15	77.33	1.557
KCl solution	0.20	77.68	1.012

3. Results

The water temperature ranges between 17.25 °C and 23.36 °C. Water had the largest infiltration distance among the three liquids, and NaCl had the smallest. This result is consistent with the assumption in Equation (1) that the infiltration distance decreases with increasing viscosity μ. Although 11 data were obtained for nine different conditions (Fig. 1), three replicates were not possible, and the significance of these data needs to be examined.

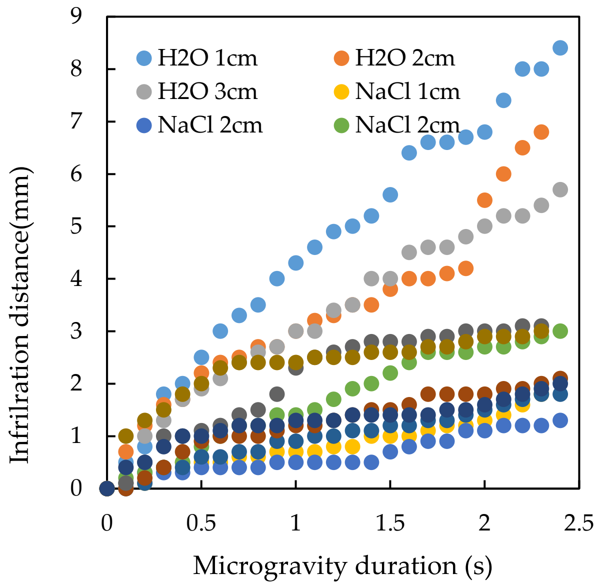

Figure 1. result of infiltration

3. Conclusions

The greatest infiltration distance was with water of the lowest viscosity. To clearly confirm that the Lucas-Washburn equation holds, comparisons need to be made at a greater variety of viscosities.

4. References

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